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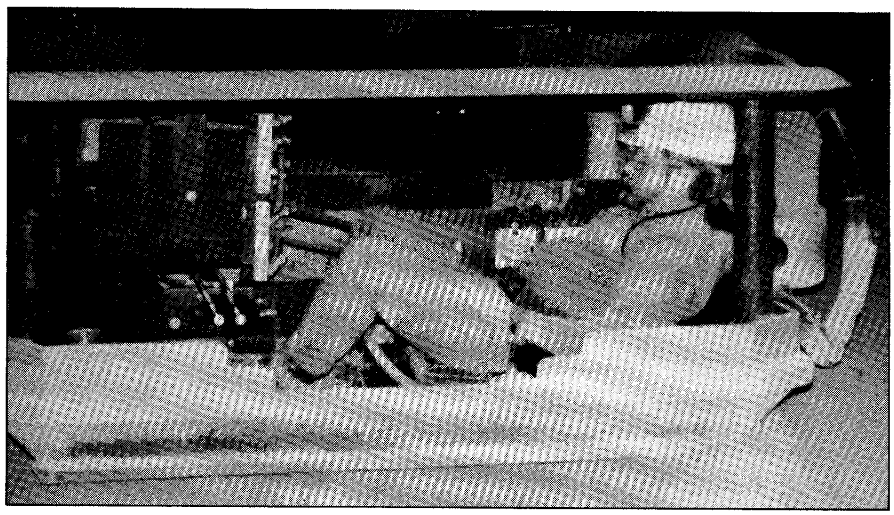
REPORT OF INVESTIGATIONS/1993

Transverse-Mounted End-Cab Design for Low-Coal Shuttle Cars

By Alan G. Mayton



United States Department of the Interior

Bureau of Mines

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UNITED STATES DEPARTMENT OF THE INTERIOR
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cfm	cubic foot per minute	in	inch
°F	degree Fahrenheit	lb	pound
fpm	foot per minute	mph	mile per hour
ft	foot	psi	pound per square inch
ft^2	square foot	psia	pound per square inch, absolute
ft^3	cubic foot	psig	pound per square inch, gauge
h	hour	V ac	volt, alternating current
hp	horsepower	V dc	volt, direct current

TRANSVERSE-MOUNTED END-CAB DESIGN FOR LOW-COAL SHUTTLE CARS

By Alan G. Mayton[1]

ABSTRACT

A prototype end-cab shuttle car (SC) design has been developed to improve protection and address ergonomic concerns of the SC operator in low coal mines. The new design features an end cab transversely mounted to the SC and equipped with a closed-circuit video system. The end cab was retrofitted to a low-coal SC and evaluated in surface trials at the U.S. Bureau of Mines. During surface trials, test operators evaluated the end-cab SC relative to visibility; cab features—space, seating, controls, and operator position; tramming—inby, outby, and turning corners; and dumping. Trials were conducted using 12 test subjects; 6 were experienced SC operators. Results of the trials were promising. Of the experienced operators, the only operator with low-coal experience gave the new design the highest rating. Four experienced operators rated the end-cab design "better" to "much better" than a standard center-driven, side-cab SC for visibility when tramming, protection from roof and rib hazards, and no change in seat position with direction of travel. This report discusses research to modify a used 21SC JOY SC, retrofit the SC with the Bureau-developed end-cab, and evaluate the retrofitted end-cab SC in surface trials.

[1]Mining engineer, Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

Historically, performance criteria such as hauling capacity and tramming clearance have been emphasized in shuttle car (SC) design. The operator cab (platform or compartment) and the ergonomic needs of the operator have been assigned a lesser priority. Experience shows this design approach results in a cab that imposes unfavorable conditions on the operator: less than adequate visibility causing the operator, at times, to lean out of the cab (fig. 1); often confining and cramped conditions causing awkward operating postures; and exposure to shocks as the vehicle moves over rough bottom.

The U.S. Bureau of Mines has done contract and in-house research to improve operator cab and canopy design as part of the Bureau's mission to enhance the safety and efficiency of mining methods (*1-8*).[2] As a result of recent research, the Bureau now offers an alternative for SC operators in low-coal mines. A goal of the research described in this report is to ensure full canopy protection from roof falls and to minimize the likelihood of pinching-squeezing accidents involving the roof or rib. Another goal is to develop a cab design that meets the ergonomic needs of the operator. Consequently, this research has resulted in a new SC configuration featuring the Bureau-prototype transverse-mounted operator cab that is usable in coal mines with 40-in working heights. The operator cab, with its novel position and orientation, offers the following improvements over a traditional operator cab and cab location: improved operator visibility, protection from roof falls and pinching-squeezing accidents, effective reclining seat for comfort and protection from shock and vibration, and sufficient working space to avoid awkward and cramped operating postures.

In May 1990, the Bureau entered into a cooperative agreement with Peabody Coal Co.'s Sunnyhill Mine near Lexington, OH. Under the agreement, the mine provided a used 440-V-ac 21SC JOY SC[3] (fig. 2) for retrofitting the Bureau operator cab.

[2]Italic numbers in parentheses refer to items in the list of references at the end of this report.

[3]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

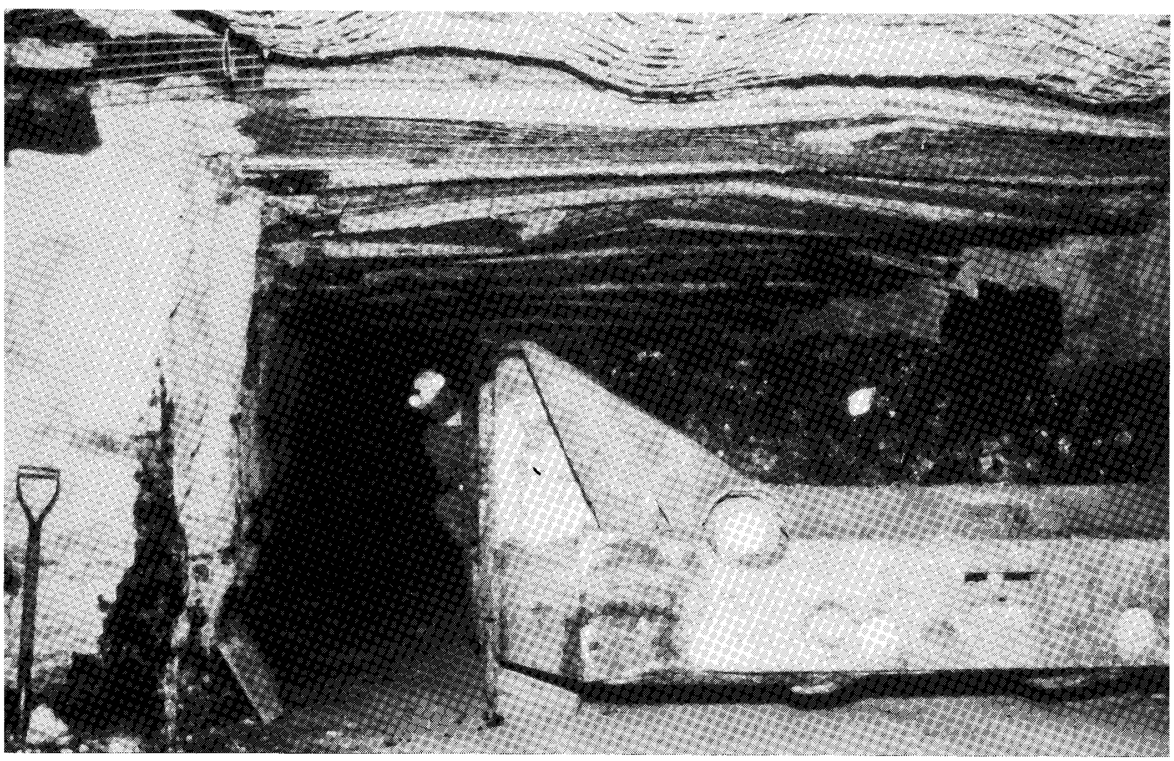

Figure 1.—Operator must lean out of cab because field of view is blocked.

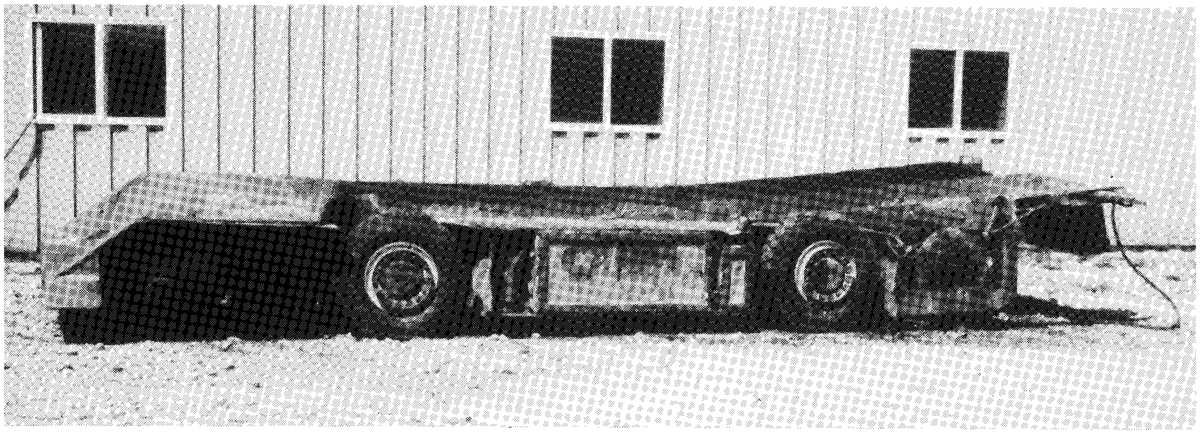

Figure 2.—Used 21SC JOY SC from Peabody Sunnyhill Mine.

ACKNOWLEDGMENTS

The author expresses his thanks and appreciation to these employees of the Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA: Albert Brautigam, electrical engineer, for his assistance with design modifications to the SC electrical system; Joseph DuCarme, mechanical engineer, for his assistance with redesigning the cable guide system and designing the end-cab mounting brackets; Robert Allen, mechanical engineer, for his assistance with design modifications to the SC hydraulic system; and William Doyak, George Fischer, and Mary Ellen Nelson, mechanical engineering technicians, for their assistance with design modifications to the SC boom and the end cab. The author also thanks JOY Technologies, Inc., Mining Machinery Division, Franklin, PA, for supplying needed technical drawings and other technical information for retrofitting the SC with the end cab.

RETROFITTING 21SC JOY SC WITH END CAB

To retrofit the Bureau-prototype operator cab effectively, various changes on the 21SC JOY SC were necessary. The main changes or modifications to the SC are discussed in the ensuing sections of this report. They concern the conveyor boom, the hopper end for mounting the novel end-mounted operator cab, and cable reel and guide arrangement. The ergonomic operator cab and closed-circuit video system also are discussed.

Specifications for the 21SC JOY SC with end-mounted operator cab are listed in table 1. The boom modifications (including the 6-1/2-in high angled sideboards) resulted in an overall frame height of 35 in measured at the boom. This height was determined in view of plans to field test the retrofitted SC in the Peabody Sunnyhill Mine, which has an average working height of 50 in. In the Sunnyhill operations, the tail boom of the continuous miner (CM) required 15 in of clearance between the SC and the mine roof for side loading of the SC. If the field testing had been planned for a mine working height of 40 in, the SC boom would have been modified for a lower overall frame height measured at the boom. Also, table 1 indicates the cab ground clearance of 3-1/2 in for surface trials. For in-mine trials, the clearance would be reduced to 1/2 in.

CONVEYOR BOOM MODIFICATIONS

Owing to its intended use for receiving and discharging the load, the boom of the SC underwent extensive reworking. The boom was disconnected from the main body of the machine, and minor repairs were made to the conveyor deck. The 1/4-in steel sides were replaced with 3/8-in plate to strengthen it for the abuse expected during the loading cycle. In addition, 6-1/2-in-high sideboards were added to the boom at an angle of 40.9° to simulate the hopper end of the vehicle and to better accommodate side loading by the miner. Angle iron sections 6 in by 6 in by 1/2-in thick were spaced along the length of the boom and used to support the angled sideboards. New 1-in steel plate replaced existing 3/4-in plate to reinforce the ends on either side of the boom and to serve as a bumper. Later, two 1- by 2-in bars were welded horizontally across these plates to enhance bumper capacity and strength. Figure 3 shows a view of the modified SC conveyor boom.

Table 1.—Specifications for retrofitted 21SC Joy SC and end-mounted operator cab

Shuttle car:		
Unit weight	lb	29,800
Overall length	ft	28.2
Frame height (with 6.5-in side boards)	in	35
Working height	in	40
Width	in	118
Conveyor width	in	56
Conveyor speed	fpm	90
Capacity (average of 3 loaded weighings)	ft^3	217
Tram speed	mph	5
Ground clearance	in	6.5
Wheel base	ft	9.3
Boom extension	in	18.5
Turning radius:		
Inside	ft	8.4
Outside	ft	21.8
Motors:		
Traction (2), 160 and 275 V dc	hp	20
Conveyor 440 V ac	hp	25
End-mounted operator cab:		
Weight	lb	3,000
Length	in	72
Height (lowest canopy position)	in	36
Width	in	37
Canopy coverage	in	40 by 77
Seat width	in	18
Cab ground clearance	in	3.5

CONNECTING OPERATOR CAB

The operator cab is centered end to end at the rear (hopper end) of the SC and oriented so the operator is facing 90° to the direction of travel. Connection of the operator cab to the SC is made with sliding brackets. To mount the brackets, 5- by 7-1/2-in slots 45 in apart were cut into the bumper. The sliding brackets are made of 1/2-in rectangular tube steel. They allow the cab to "float" along the mine bottom. A 3- by 5-in inner bracket slides within the 5- by 7-in outer bracket (figure 4 top and bottom).

The inner bracket has 3/8-in steel welded to each side for enlarging the perimeter of the inner bracket. In addition, the inner bracket features a 1-1/4-in-wide and 18-in-long slot through which a 1- by 3-in hardened dow pin passes. The pin and slot arrangement limits the total movement of the cab to 17 in and the vertical disengagement between the inner and outer brackets to 9 in, when the cab moves down relative to the SC, and 8 in the up direction.

Furthermore, a steel collar, 1 in thick by 2 in wide, and nearly three-quarters of the perimeter of the outer bracket, is used to reinforce the outer brackets.

RELOCATION OF CABLE REEL

Since loading now would take place at the opposite end of the SC, the power-cable reel and guide-pulley arrangement needed to be relocated. These items were moved from the right side of the boom (viewing from the new end-mounted cab) to the former operator compartment located on the left side of the SC between the wheels. The cable reel was rotated 90° on end in its new location to avoid increasing the width of the SC.

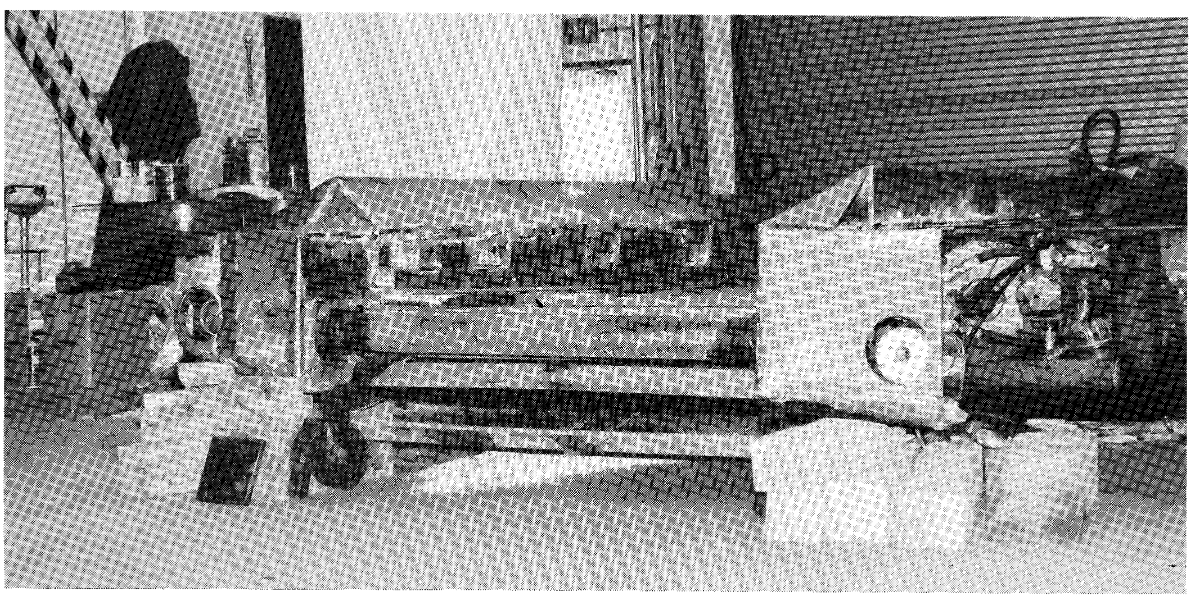

Figure 3.—Modified SC conveyor boom.

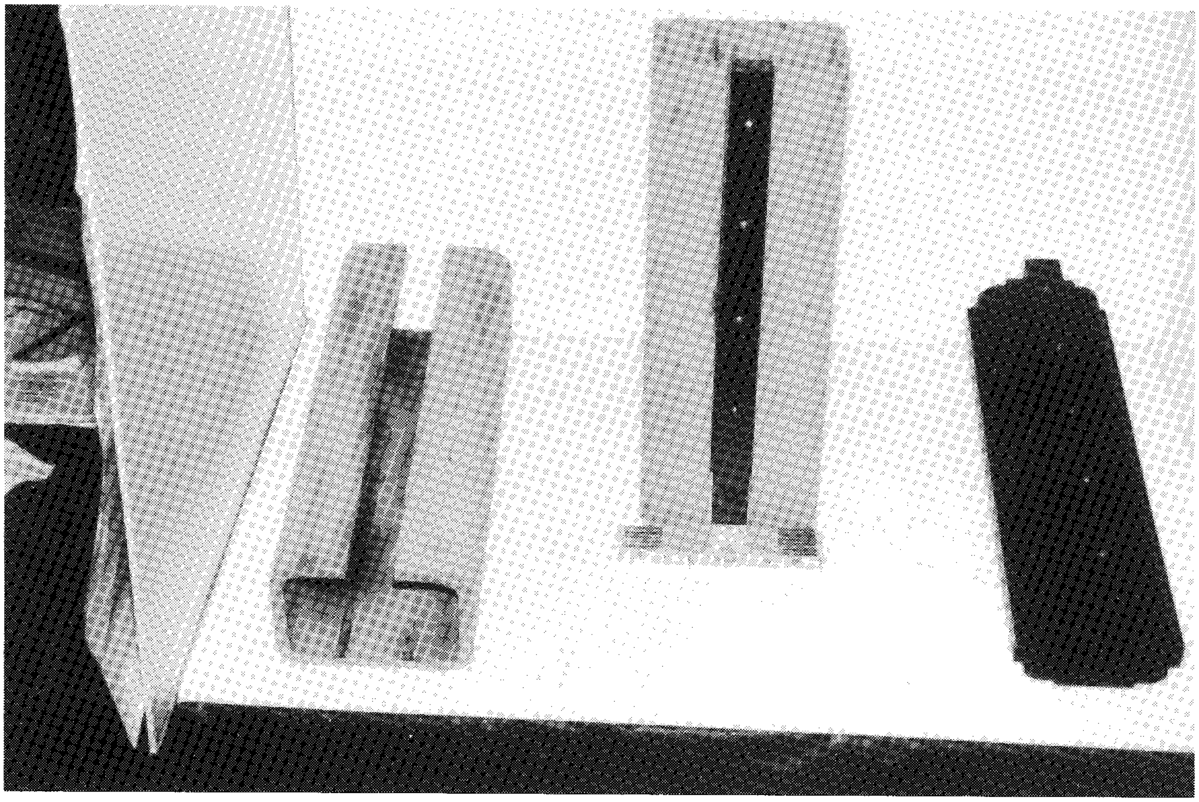

Figure 4.—Sliding brackets that connect end-mounted cab to SC (top and bottom).

Similarly, the cable guide system needed revision. A roller arrangement was added above and to the side of the tire nearer the end cab. In addition, cable guide eyes similar to the guide on the cable reel spooling device were added along the sideboard of the hopper. These direct the cable to a redesigned guide-pulley arrangement that uses smaller pulleys than the previous arrangement (fig. 5).

CLOSED-CIRCUIT VIDEO SYSTEM

Even though the end-mounted cab significantly improves operator visibility during tramming (not during loading and dumping), blind areas are not eliminated entirely. Hence, the need for the closed-circuit video system. The primary purpose of the video system is to assist the SC operator in viewing areas blocked by the loaded coal. The two main instances when SC operators will use the video cameras are when loading at the miner to minimize coal spillage and at the discharge area when their view will be partially obscured by the load. In this case, the SC operator must rely on the video system a great deal to maneuver and discharge the load.

The video system consists of two small (palm-size) monochrome video cameras and a monitor with a 9-in screen. Each of these is housed in an explosion-proof (XP) enclosure certified by the Mine Safety and Health Administration. The enclosures contain viscoelastic foams, extra-soft and medium, to protect the cameras and monitor from damaging shock and vibration. These materials were selected after placing the camera and monitor individually on pieces of the extra-soft and medium foam materials, respectively, and observing the static deflection of the material. Figures 6 and 7 show the XP enclosures containing one of the video cameras and the monitor.

One video camera and the video monitor were subjected to more than 50 h of shock and vibration in a Bureau laboratory to determine how well they would function and hold up under such conditions. The 50 h equates to approximately 10 shifts of SC operation, given a typical 5-h actual operating time for a SC on a CM section (*9*).

The procedures used for the shock and vibration evaluation were as follows. Both the camera and monitor, in their respective XP enclosures, were fastened securely to the vibrating platform, and a target was placed in front of the camera. The image of the target was, in turn, transmitted to the monitor screen. The camera and monitor were checked to ensure that a distinct image of the target appeared on the monitor screen prior to starting the platform with the selected SC operating cycle. Visual checks of each enclosure and the image on the monitor screen

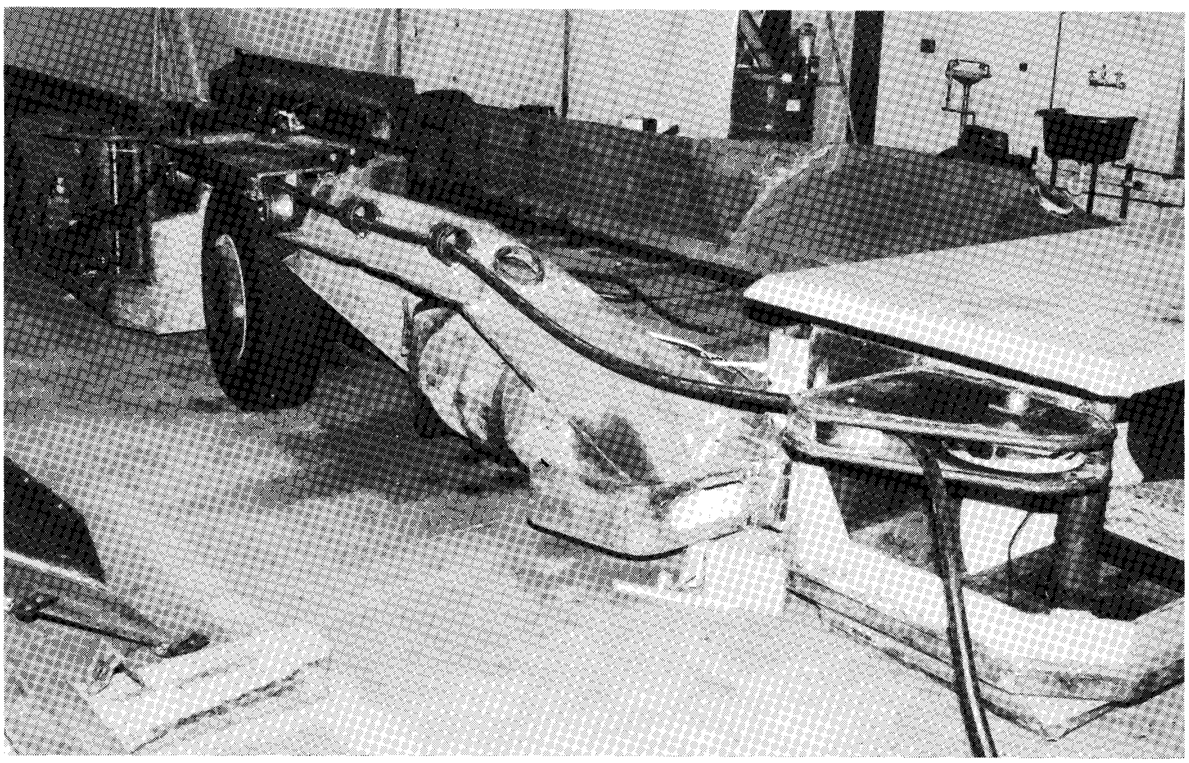

Figure 5.—Revised cable reel and cable guide arrangement.

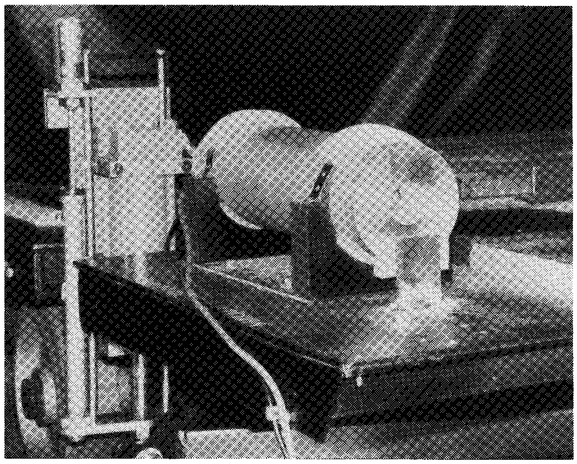

Figure 6.—Explosion-proof enclosure housing a single video camera.

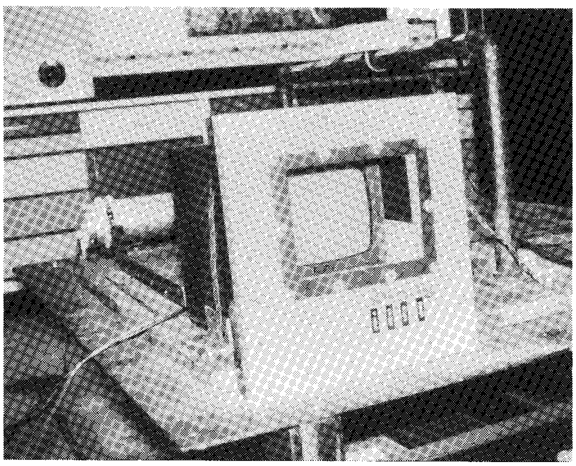

Figure 7.—Explosion-proof enclosure housing video monitor.

were made intermittently throughout the vibrating interval. The video components were then subjected to vibration in the vertical dimension on the computer-controlled vibration platform at levels of shock and vibration typical of a SC operating in the "tramming empty" and "discharging load" cycles. The other dimensions of SC shock and vibration (side-to-side and fore-and-aft) were deemed insignificant for the purposes of this evaluation.

The continuous shock and vibration intervals ranged from 1 to 7 h, with an average interval of 4.6 h of continuous shock and vibration. Shorter periods resulted from necessary stoppages of the platform primarily because of a damaged coaxial cable (corrected by relocating the cable gland in the monitor enclosure), broken and ineffective clamps for securing the enclosures to the platform, and a faulty hydraulic cylinder on the vibration platform.

Recordings of shock and vibration were collected from an operating SC on the production section of an active underground mine. The "tramming empty" and "discharging load" cycles represented the most severe conditions of shock and vibration. Approximately half of the total time was allotted to vibrating the enclosures in each SC operating cycle. Both the camera and monitor were still operating at the end of the test with no apparent damage. In summary, the evaluation shows that the video system components (with the viscoelastic foam materials used in the XP enclosures) are capable of withstanding, for a period of time, some conditions of SC shock and vibration occurring in an underground mine.

The two video cameras are arranged on the SC so that one camera is mounted in a fixed position at the end of the boom. This camera is equipped with a wide-angle lens, which enables the operator to see any obstacles, other workers, etc., when maneuvering the loaded SC at the dump. The second camera is on the opposite side of the SC and mounted above the controller. This camera has a 90° panning feature that is designed to operate remotely with a push-pull cable from the end cab. (The push-pull cable was not installed for surface trials.) A selector is located in the operator compartment to permit the operator to switch scenes on the monitor between the two cameras.

The monitor, within its XP housing, is mounted to the left underside of the canopy (looking inby) above the tram foot pedal. It is held by a steel-angle bracket and a sliding mechanism that allows small increments of vertical tilting and movement in the fore-and-aft direction. Four control knobs protrude through the front cover of the enclosure for the on-off, vertical hold, brightness, and contrast controls.

PNEUMATIC SELF-CLEANING SYSTEM FOR CAMERA ENCLOSURE WINDOW

Both camera enclosures are equipped with an air-wipe system to keep dust from accumulating on the enclosure windows. Air (20 cfm total at 20.7 psia, 68° F) is supplied by a belt-driven, rotary-vane, oilless compressor powered with a hydraulic motor. The components of the system include a diffusion ring and mounting assembly. The diffusion ring has 12 equally spaced, 1/8-in-diameter holes drilled around its circumference. The holes are drilled at right angles to the long axis of the enclosure. Air delivered by the compressor enters the enclosure through two inlet ports, 180° apart, in the diffusion ring mounting assembly and passes on through the holes in the ring. The hole pattern causes opposing streams of air to strike one another, creating a high degree of turbulence in front of the enclosure window. Laboratory tests have shown that the air-wipe system, delivering 7.5 cfm at 2 psig of air, will prevent dust from accumulating on the enclosure window, and will remove dust that may exist on the window prior to startup of the air-wipe system. The compressor delivers approximately 10 cfm of air to each camera.

ERGONOMIC, END-MOUNTED OPERATOR CAB

The operator cab is designed to give the operator more space to operate the machine from a comfortable operating position (fig. 8). Original operator controls were retrofitted from the former operator cab to the new locations within the end-mounted cab. The controls include hydraulic for steering, conveyor clutch, and service (foot) brake; and electrical switches for lights, the pump and traction motors, conveyor direction, tramming "butterfly" (foot) pedal, panic bar, and selecting displays between the two cameras. These controls were placed within the operator cab with the aid of a draft of Proposed Society of Automotive Engineers XJ1314 Human Factors Guidelines for Mobile Mining Equipment, January 1, 1991. Additionally, input from two individuals, approximating the larger (95th percentile male) and smaller (5th percentile female) operators, was used in pinpointing control locations. These persons sat in the operator compartment, handled the controls, and gave verbal feedback as to the ease in reaching and activating and deactivating a control lever or switch. The controls were mounted along either side of the operator seat within the SC operator's envelope of comfort and reach.

The seating in the cab features a reclining contoured seat with a contoured headrest. The seat pan tilt can be set at three angular positions; 0°, 11.7°, and 23.4°. Similarly, the seat back positions include 53.1°, 45°, 36.9°, 28.8°, and 20.7°. Dimensions of the seat and headrest are seat pan, 15 in long by 18 in wide; seat back, 22 in long by 17 in wide; and head cushion, 5 in high by 10 in long by 4 in wide.

HYDRAULIC AND ELECTRICAL MODIFICATIONS

Other modifications were done concerning the electrical and hydraulic systems of the SC. These modifications were necessary to operate the video system with pneumatic self-cleaning of the enclosure window, to make the conveyor operate in both directions, and to accommodate the use of two video cameras.

The hydraulic modifications included replacing the hydraulic pump with a reversible pump and adding the air compressor and hydraulic motor to power it. A schematic of the modified hydraulic system appears in figure 9.

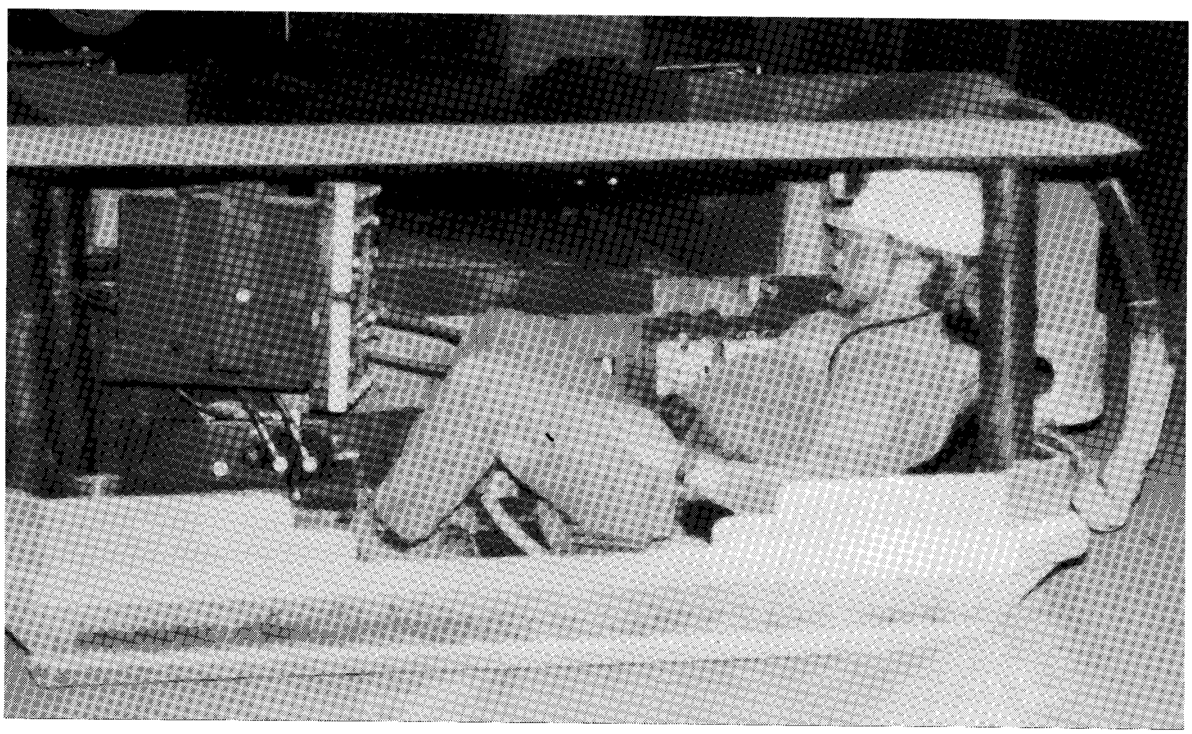

Figure 8.—Bureau-prototype end-mounted cab for low-coal SC.

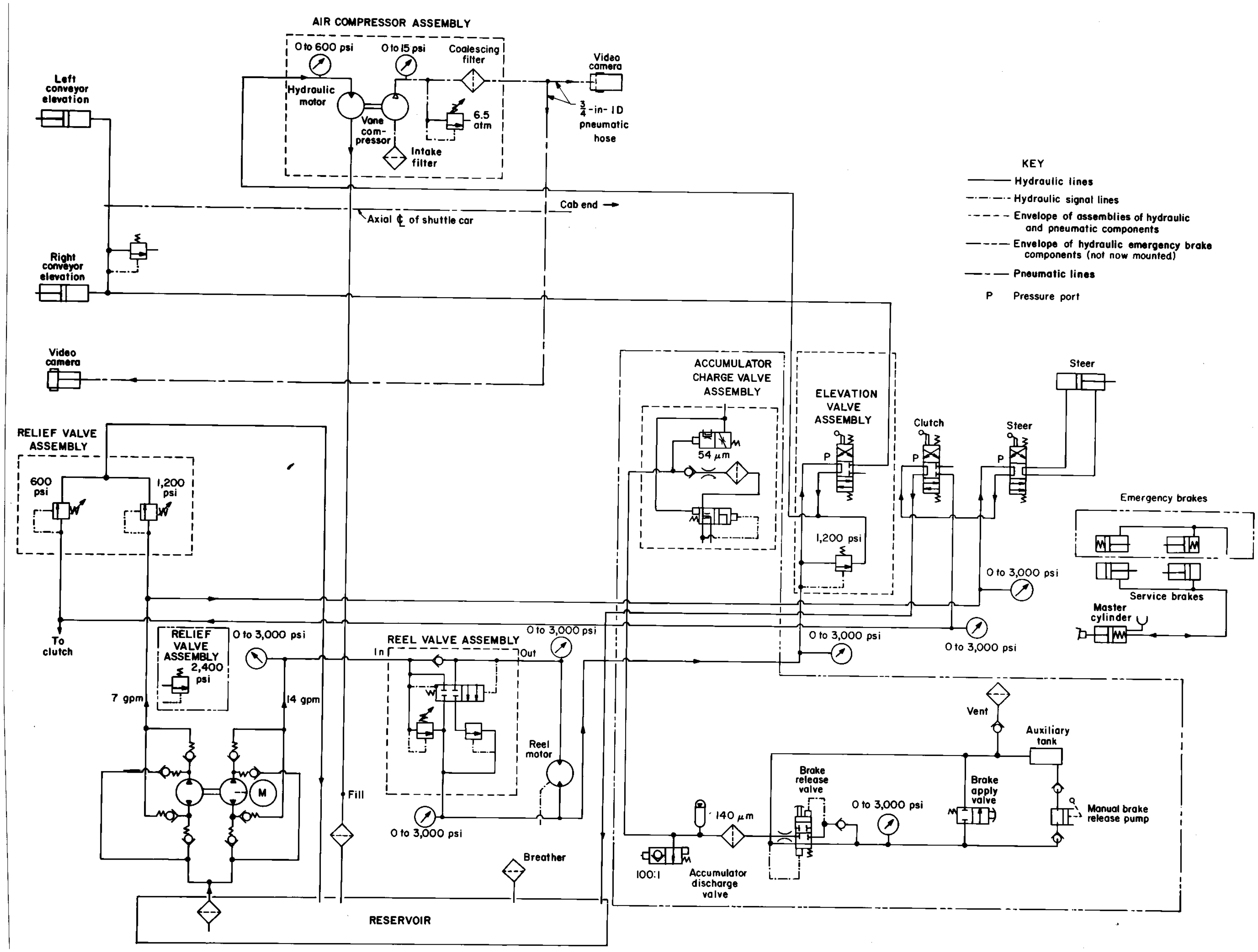

Figure 9.—Modified SC hydraulic system.

Difficulty with operating the reversible pump was experienced when it was first installed and operated. The pump experienced cavitation caused by suction pressures in excess of the maximum 2.5 psi specified by the manufacturer. This occurred largely because of excessive cracking pressure (6 psi) for 3/4-in check valves, and line losses; and to a lesser degree because of a partially clogged suction filter. Remedial action to correct the problem with the pump circuit included replacing four 3/4-in check valves with 1-in valves having a cracking pressure of 1 psi, replacing the 1-1/4-in suction hose and 3/4-in lines with 1-1/2-in hose and 1-in lines, and cleaning the suction filter, suction tube, and reservoir.

The inby side of the operator cab included a movable plate to prevent coal from spilling into the cab and onto the operator. Since the hydraulic control and cylinder for moving the plate up and down were unavailable, the plate was tack welded in place for surface trials. Having the plate in a fixed position proved adequate for the surface evaluation of the retrofitted end-cab SC.

Electrical modifications included the addition of a transformer to power the video monitor and cameras, a reversing contactor, circuit breakers, mounting brackets for the preceding items, and a modified circuit breaker switch handle. Two other modifications consisted of unplugging a spare gland opening in the controller and rerouting a cable to free up an additional gland opening in the controller. Figure 10 shows a schematic of the modified electrical system.

Reversing the conveyor also required cutting back about 8 in of the plate extending from the bumper over the tail end of the conveyor to prevent the conveyor from becoming jammed with pieces of coal or rock. In addition, work had to be done on the flights for reversing the conveyor. Several flights on the underside of the conveyor broke off after being bent severely. Afterwards, thorough lubrication of the chain curtailed this problem. Other bent or deformed flights were removed and replaced with fabricated ones. Moreover, 2 to 3 in of the conveyor deck was cut off at the boom hinge shaft to prevent flights from becoming jammed and hung up when reversing the conveyor.

SURFACE TRIALS

At the conclusion of the retrofitting work on the SC (including debugging of the conveyor pump motor, flights, and chains), the machine was tested in the Bureau's Mining Equipment Test Facilities at the Pittsburgh Research Center (PRC). A 5,076-ft^2 test course (fig. 11) was set up to simulate two mine entries and a crosscut. Fluorescent orange traffic pylons with approximately 6-ft-long sticks (painted the same color) were used in marking off the course. The main entry was about 150 ft long. The secondary entry, adjacent to the main one, was about 35 ft long. The crosscut was about 100 ft long and included a 20-ft-wide structure that was formerly part of a simulated mine entry. Widths of the entries and other segment of the crosscut were 18 ft. The retrofitted SC was evaluated on information received from 12 Bureau employees at the PRC, who operated the SC through the test course. A questionnaire with 9 main questions, providing 54 pieces of information, was used to gather the information from the test subject operators. (Six other questions were added to the questionnaire later.) Questions covered topics such as field of view, maneuvering the SC around corners, tramming inby and outby, tramming loaded and empty, the closed-circuit video system, cab space, cab "floating," and seating.

TEST SUBJECTS—SC OPERATORS

The 12 test subjects selected to operate the retrofitted SC ranged from 30 to 53 years of age; 10 were males and 2 were females. The sizes of the subjects ranged from 5 ft 2 in, 118 lb to 6 ft, 260 lb. Six of the twelve subjects were former SC operators with one having SC operating experience in low coal. The SC operating experience of these subjects ranged from 1 to 8 yrs, whereas overall mining experience varied from 5 to 20 yrs. The former low-coal SC operator had experience in a mine working height down to 38 in, whereas the other former SC operators had experience in mine working heights of 60 in and above. Two test subject operators had experience running other heavy equipment such as continuous miners (CM), front end loaders (FEL), cranes, trucks, and SC on the grounds of the research center. The test subjects were three coal miner mechanics from the PRC experimental mine, three mechanical engineering technicians, two mining engineers, a civil engineer, a mining industry research specialist, a training research specialist, and a computer programmer analyst.

TEST PROCEDURES

Each subject test operator was given an explanation of the different controls and how they functioned. Then the operator was given the opportunity to become familiar with the operation of the retrofitted SC by tramming in the inby and outby directions and making turns into the 18- and 20-ft-wide crosscut segments (fig. 12). Afterwards the test operator was instructed to tram inby to have the SC loaded in the main entry. The operator received a

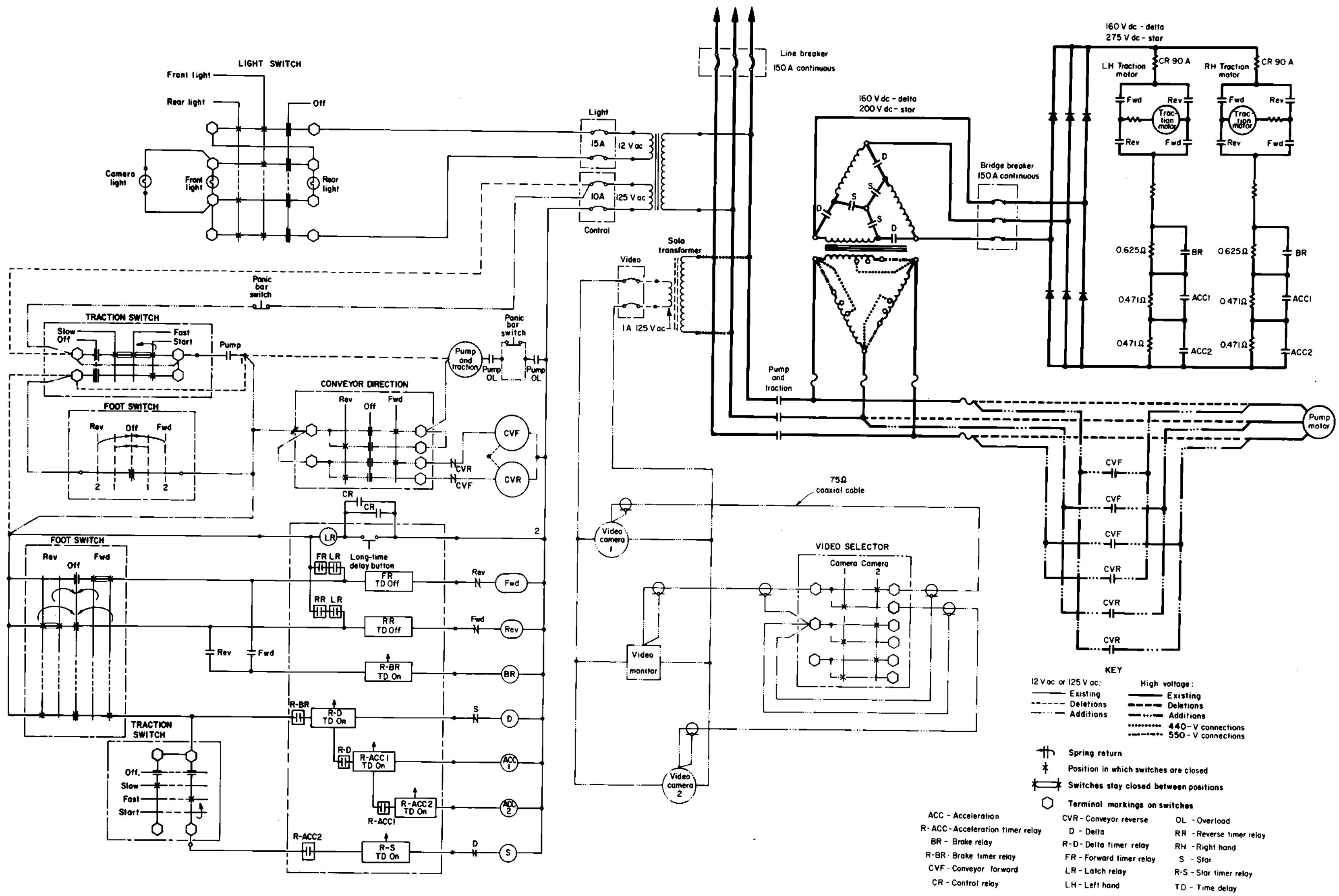

Figure 10.—Modified SC electrical system.

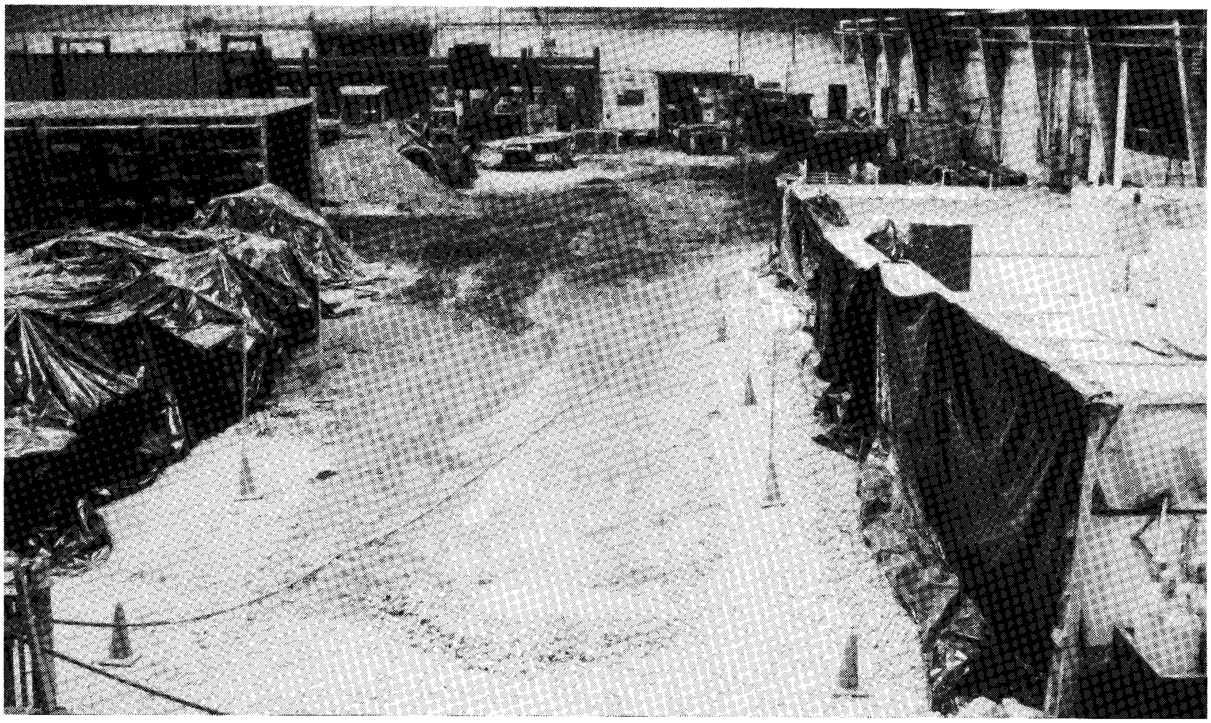

Figure 11.—Test course for surface trials.

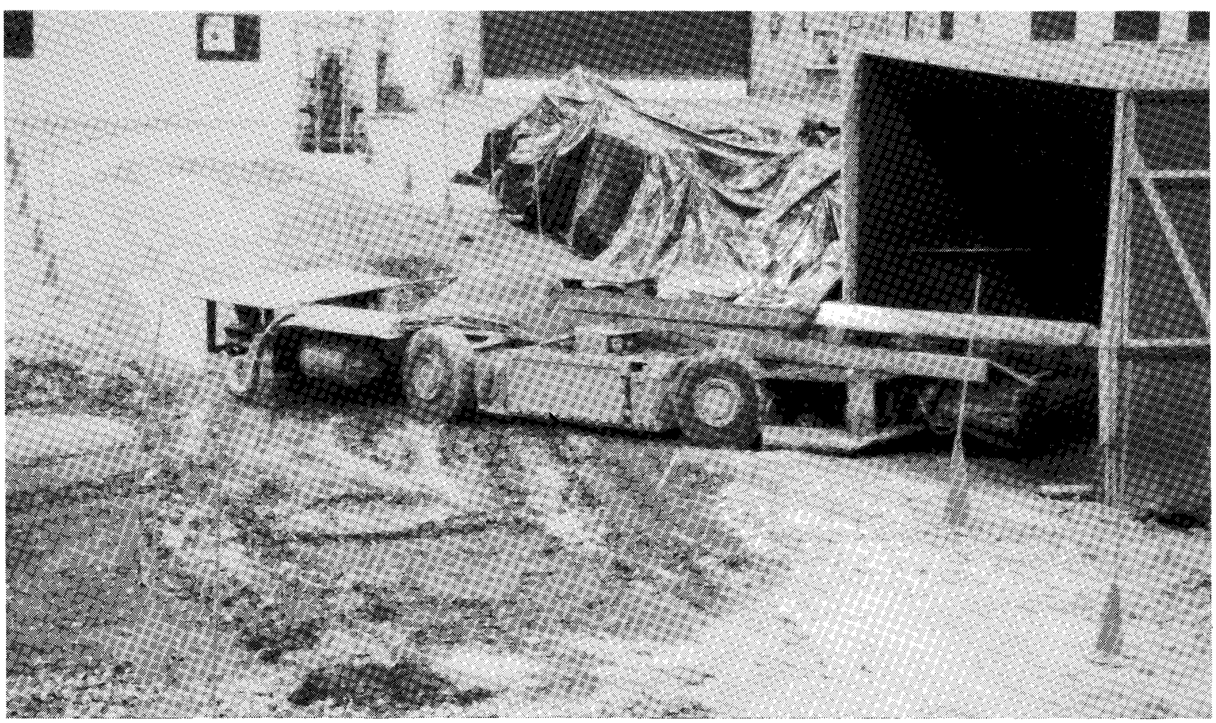

Figure 12.—Test subjects maneuver end-cab SC during surface trials.

load of run-of-mine (ROM) coal, trammed outby with the load along the main entry, made turns into the right hand and left hand portions of the crosscut, and completed the simulated duty cycle by dumping the load onto the ROM coal pile. After operators had completed their test sessions, they were interviewed using the questionnaire.

Loading

Initially, plans were to load the shuttle car with a used low-coal CM, a Jeffrey 101 MC. However, the stub tail boom of the CM (designed for use with continuous haulage) did not provide the reach or the clearance for effective straight and side loading. Loading, therefore, was accomplished with a John Deere 544B FEL. Attempts were made to ensure the manner in which the SC was loaded approximated that of an actual underground mining situation. This was done with the FEL loading the shuttle car from the side and piling coal into the modified boom end of the machine. When the coal pile on the conveyor reached a certain level, the SC operator would jog the conveyor in reverse to move the coal pile into the empty end of the SC. This process was repeated until the coal in the SC reached the cab end of the conveyor. The operator would then tram outby and eventually end up at the dump point to discharge the load.

Haulage Capacity

Before trials began with the test operators, an attempt to evaluate the capacity of the SC was made using specifications from the manufacturer and a pair of portable truck scales (fig. 13). The SC was weighed empty using the scales under one set of wheels at a time. The weight of the empty SC was 29,800 lb. Weighing the SC with three separate loads produced ROM coal weights of 12,850 lb, 8,700 lb, and 11,050 lb. JOY's specification for load capacity of the model 21SC having 56-in-wide conveyor with 6-in side boards was 8,750 lb. Thus, the capacity of the SC was not diminished by modifications and the "unorthodox" style of loading and met or exceeded the manufacturer's specification.

Trials With Full-Floating End Cab

The SC was first tested with the compartment functioning in the full-floating condition; i.e., the cab could "float" upward and downward relative to the frame of the SC. Observing the trials and responses from the test operators led to the conclusion that this arrangement had some serious shortcomings. The cab tended to plow the coarse and fine gravel overlying the red dog and clay bottom of the test course. This affected maneuvering the SC significantly. Moreover, the outer member of the sliding brackets welded to the SC became a visual obstruction for the operator when the cab moved to a level lower than the SC frame (fig. 14). Furthermore, the plowing action of the cab, the accompanying noise, and the less than desirable steering adversely affected the concentration, confidence, and subsequent performance of each operator to one extent or another.

Results From Testing Full-Floating End Cab

Figure 15 shows the total ratings for the 12 test subjects for 33 selected parameters of the full-floating, end-cab SC. The histogram shows that the experienced operator in low coal had the highest cumulative rating of all test subjects

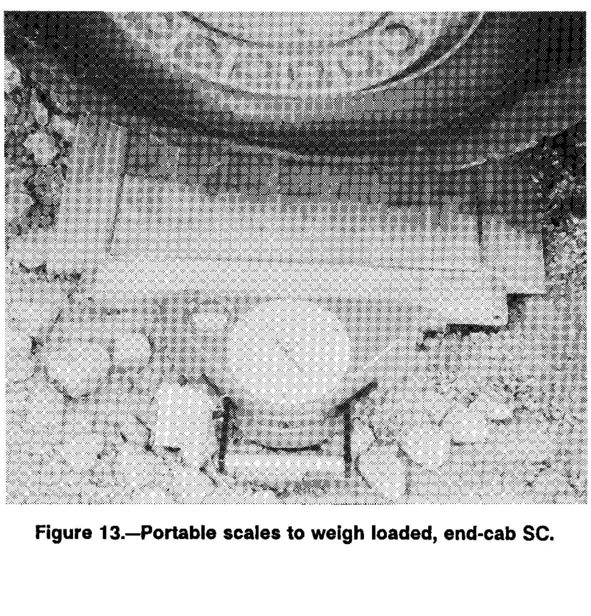

Figure 13.—Portable scales to weigh loaded, end-cab SC.

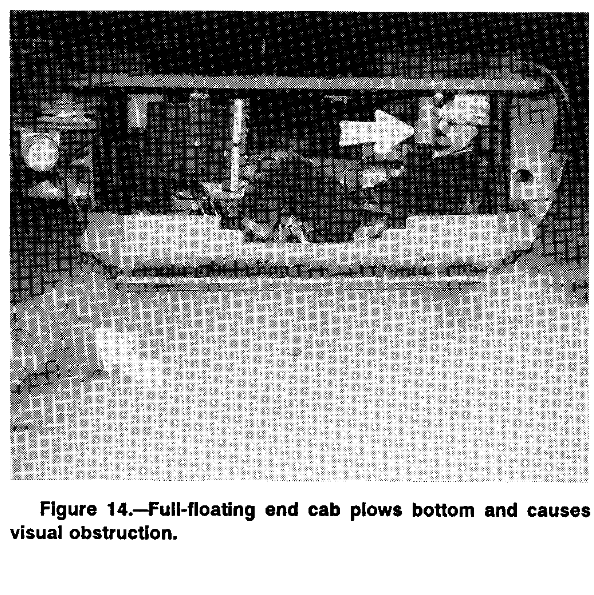

Figure 14.—Full-floating end cab plows bottom and causes visual obstruction.

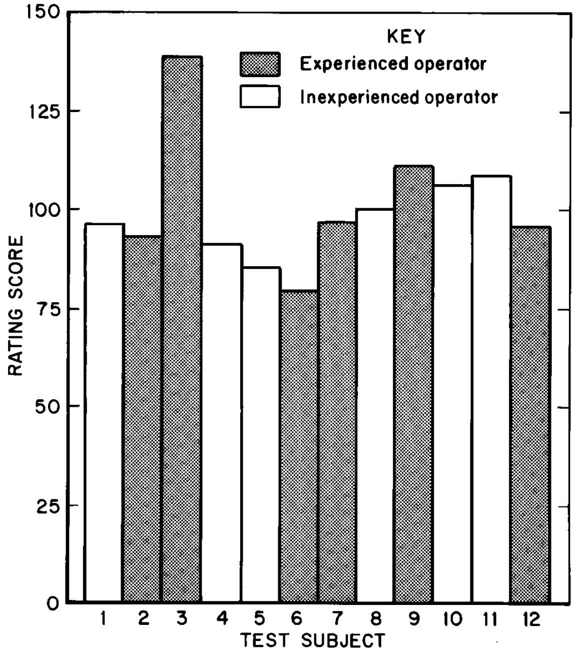

Figure 15.—Total rating scores of 12 test subjects for 33 operating parameters of full-floating, end-cab SC. (Rating score of test subject 8 is based on 32 parameters. Test subject 3 is the operator with low-coal experience.)

with 138 of a possible 165 total points. The second and third highest cumulative ratings, 111 and 109, were given by experienced and inexperienced SC operators, respectively. The lowest rating of 79 was given by an experienced operator.

The mean ratings of the 12 test subjects (using a scale of 1 to 5) for individually selected operating parameters of the full-floating, end-cab SC are shown in figure 16. The highest ratings of 3.92 were given for tramming outby in terms of visibility and the location of the video monitor in the cab. The third highest rating of 3.83 was recorded for the foot controls in terms of ease of recognition, reach, and operation. The hand controls, cab space, and comfort of the ride were "good" to "very good" with ratings of 3.42, 3.33, and 3.25, respectively. The remaining items in the figure were rated "fair" to "good" with ratings of 2.00 to 2.83. The lowest rating of 2.00 was recorded for tramming inby.

A comparison of ratings between experienced operators and the other test subjects for the same operating parameters is shown in figure 17. Ratings for the two groups were similar for a majority of the parameters. Noteworthy differences in the ratings are shown for tramming outby, foot controls, comfort of the ride in terms of the seating, cab space, and operator position relative to the direction of travel. Here the experienced operators, compared with the other operators, had the higher ratings, 4.17 to 3.67, 4.11 to 3.56, 3.83 to 2.83, 3.50 to 3.00, and

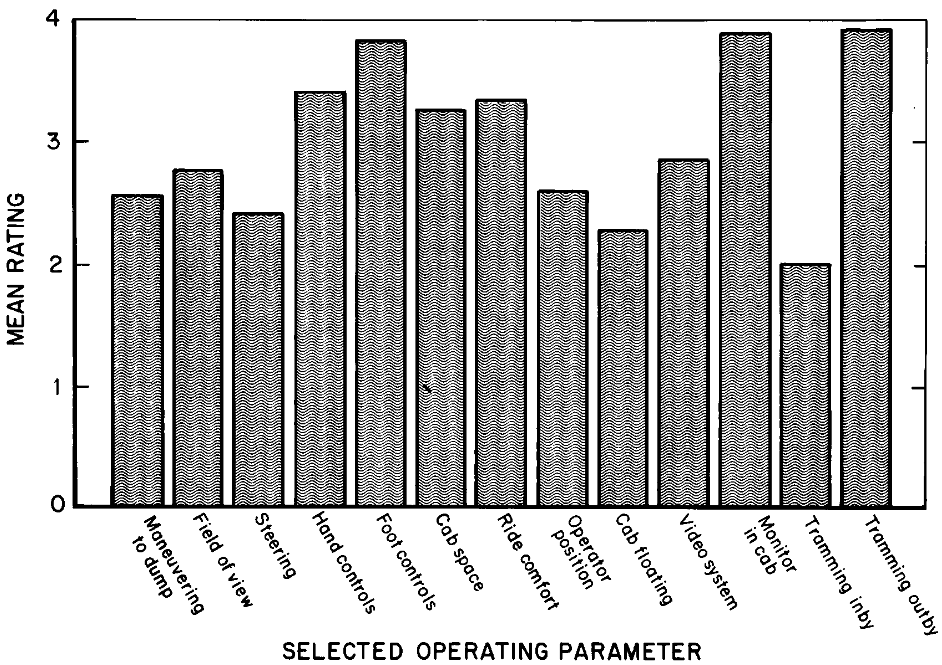

Figure 16.—Mean total ratings of 12 test subjects for selected operating parameters of full-floating, end-cab SC (very good = 4, good = 3, fair = 2, poor = 1).

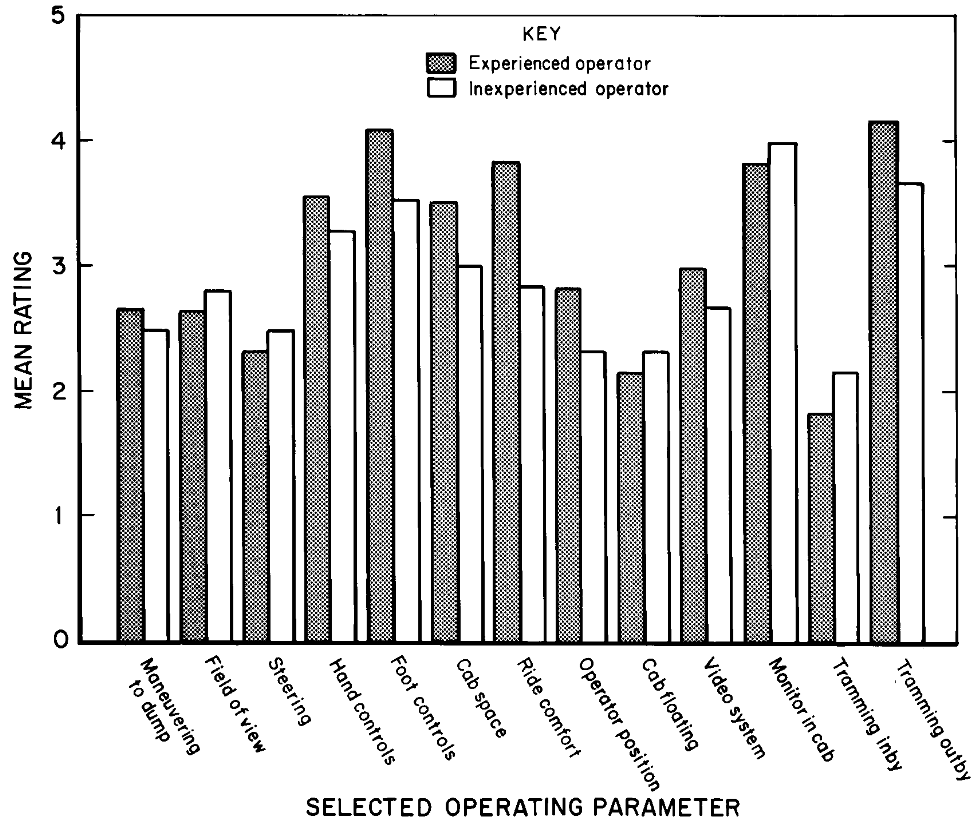

Figure 17.—Mean ratings of experienced versus inexperienced operators for selected operating parameters of full-floating, end-cab SC (excellent = 5, very good = 4, good = 3, fair = 2, poor = 1).

2.83 to 2.33, respectively. The experienced operators also gave a higher rating for the hand controls, maneuvering to dump, and the effectiveness of the video system. The lowest rating is shown for tramming inby, where the experienced operators gave a 1.83 rating compared with 2.17 for the other operators.

Discussion

Difficulties

The difficulties test subjects experienced at the outset of a test session concerned the following: visibility tramming inby, adjusting to the steering (maneuvering or handling) of the SC, becoming accustomed to the speed of travel, judging to make turns, the plowing and dragging action of the cab, judging the location and orientation of the SC with respect to the mine entry and crosscut, and the fore-and-aft adjustment of the seat. In the majority of cases, however, these diminished, at least somewhat, by the end of the test session. Thus, it is reasonable to conclude that these difficulties would continue to diminish over time with increased experience and familiarity of operating the end-cab SC.

Strengths and Weaknesses

The strengths and weaknesses of the full-floating, end-cab SC as perceived by the test subject operators are as follows:

Strengths	*Weaknesses*
1. Visibility outby.	1. Visibility inby.
2. Space in the cab.	2. Use of the video system.
3. Seat and ride comfort.	3. Plowing-dragging of cab.
4. Control layout and operation.	4. Full-floating bracket obstructs view inby when cab "floats" downward.
5. Operator more out of dust produced from CM.	5. Exposure to end collision.
6. Operator protection (from ribbing hazards particularly).	6. Cramped space for large operators.
7. Increased production from extended cut mining (perceived by one test subject).	7. Extra maneuvering to dump.

The strengths noted were unrestricted visibility tramming outby, space in the cab, a relatively unjarring ride, position and relative ease of using the hand and foot controls, and operator protection. The low-coal SC operator expressed the latter two strengths as "it's got a really compact kitchen" and the end-mounted design "... is really a benefit, because it keeps you out of a lot of danger." From his viewpoint, the end-cab SC took less effort to operate because of the control movement and layout and no change in seating position. He added that with a side cab, an operator is often out from under the canopy in order to see, and thus is exposed to pinching-squeezing hazards from the rib, posts, cribs, etc.

In contrast, the major weaknesses indicated were visibility tramming inby empty and loaded, depth perception in using the video system, steering, and plowing-dragging of the cab and its effects. Other weaknesses noted were the cab "floating" below ground level, resulting in an obstructed inby field of view for the operator; more exposure of the operator on the outby side to a collision with another vehicle, rib, etc.; cramped space for larger operators; and the extra maneuvering necessary to discharge the load.

Furthermore, test subjects were asked about whether they felt the end-cab SC would hinder or enhance production. All but one felt it would hinder production in view of the weaknesses noted above. In summary, the general feeling of the test operators, particularly the experienced ones, was that the full-floating end cab needed some definite improvements before it was fit for production use.

Recommended Improvements

The test operators were asked to suggest how the end-cab SC could be improved. The suggested improvements for the full-floating, end cab are

1. Improve visibility for direct and video camera viewing.
2. Move camera panning control lever on underside of canopy several inches inby to eliminate head bumping hazard.
3. Restrict downward travel of cab "floating" to eliminate visual obstruction and plowing-dragging action, and for better maneuvering.
4. Provide more space in cab for larger operators.
5. Modify control locations and use smaller central panel for all controls to better optimize cab space, reach, and ease of operation.
6. Relocate conveyor clutch control more toward foot of cab, and weld extension arm on it or make control hand operated.
7. Drill holes into bottom of compartment for drainage of water.
8. Repair steering and change to more conventional style such as an orbital unit.
9. Employ color cameras and monitor to enhance visual perception with video system.
10. Modify location for movable video camera and provide movement capability for stationary camera.
11. Offset cab toward cable side of SC relative to conveyor to improve visibility.
12. Improve seat to allow for finer incremental adjustment.
13. Provide a panic bar instead of a button for easier reach and operation.
14. Raise cab higher to improve visibility.

Partial-Floating End-Cab Trials

With results of the full-floating trials in mind, a second set of trials was conducted with five test subjects from the first trials: four experienced operators and an inexperienced operator. Considering the suggested improvements above, the float mechanism of the end cab was altered to limit downward travel (fig. 18). This was done easily and

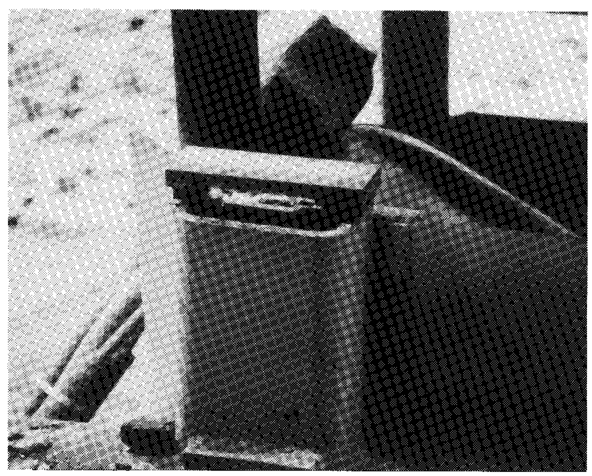

Figure 18.—Stops welded to inner section of sliding brackets for partial-floating end cab to prevent downward movement.

seemed to carry the most impact for operating the end-cab SC. In addition, the movable camera mounted atop the SC controller was moved out toward the edge of the controller case.

The trials were conducted in a similar fashion to the earlier trials and the test operators were asked the same questions from the questionnaire. Results were dramatically more favorable. Figure 19 shows mean ratings of five retested operators for the full-floating versus partial-floating end cab. A twofold increase occurred in the rating for tramming inby in terms of field of view. Field of view, in general, also increased nearly a full rating point from 2.80 to 3.60. Moreover, the steering or maneuvering and handling of the SC increased from 2.40 to 3.60, although no changes were made in the steering. Furthermore, the rating on the "floating of the cab" increased nearly twofold from 2.20 to 4.20. All other parameters show a modest to slight increase attributed to the partial-floating (upward movement only) of the cab, the elimination of debris coming into the cab, the reduction of noise from the dragging-plowing, and the increased familiarity of the test subjects with operation of the end-cab SC.

The four experienced operators compared both the full-floating and partial-floating, end-cab SC with the standard side-cab design. The parameters used in the comparison are shown in figure 20. Note the high ratings for visibility, operator position, protection from roof and rib hazards, and no change in seating position when changing the direction of travel. Mean rating scores of 4.5, "better" to "much better," were given for these items comparing the partial-floating, end-cab SC with the standard side-cab SC. The rating of "same," 3.00, is shown for only the loading procedure. All other ratings of the partial-floating, end-cab SC compared with the standard SC are above the 3.0 rating.

Finally, the total cumulative rating scores for the five retested subjects for the 33 operating parameters were compared for the full-floating and partial-floating, end-cab SC. These scores are shown in figure 21. All scores increased from 10% to 52% and dramatically show the effect of limiting downward travel of the end cab. In part, this increase is attributed also to greater familiarity of the test subjects with operation of the vehicle. The experienced low-coal operator again scored highest in the ratings. Interestingly, the experienced operator who had the lowest score of the 12 test subjects for the full-floating end cab had the greatest increase (52%) in the cumulative ratings compared with his score for the partial-floating end cab. Although his experience was limited to mine working heights of 60 in or above, his negative view of the end-cab SC became a very favorable view as a result of making the end cab partial-floating instead of full-floating.

In-Mine Production Trials

In-mine production trials were planned in conjunction with the Sunnyhill Mine in eastern Ohio. However, the mine closed and the company was unable to work out suitable arrangements with another of its mines.

CONCLUSIONS AND RECOMMENDATIONS

The surface trials of the retrofitted end-cab SC provided very encouraging results. Although the trials were not entirely conclusive as to how the end-cab SC will perform in a production mode underground, they showed this new design promises definite benefits in safety from roof and rib falls for the low-coal SC operator. Strong indicators of this were the comments and ratings by an experienced low-coal SC operator and other experienced operators. In the view of these experienced operators, the end-cab design does enhance significantly operator safety from roof and rib hazards as well as visibility when tramming. The transverse-mounted, end-cab SC design offers a more "operator friendly" alternative to traditionally designed SC operator cabs in terms of cab space, controls, seating, and no change in seating position when changing direction of travel. The closed-circuit video system is an important feature of this new, alternative SC design in helping the operator see blind areas obscured by the load of coal and SC frame. The system, however, will require some maintenance, and experienced operators may require additional time to get used to the design. The hauling capacity of the retrofit SC was not diminished, as shown by several scale weighings, but met or exceeded the manufacturer's specifications for the unmodified version of the SC. From a production viewpoint, the end-cab arrangement allows manufacturers to design a wider SC given the space gained by transferring the operator cab from the side to the end of the machine. This can result in increased haulage capacity. Furthermore, the new alternative will permit mining deeper cuts with a remotely controlled CM,[4] and thus increase the depth of cut by an additional 15 ft compared with the depth when a center-driven, side-mounted cab design is used. The only major drawback to the end-cab design noted is the extra maneuvering needed to discharge the load. This, however, should be more than offset by enhanced safety for the SC operator, the production benefits noted (wider SC and deeper cuts), and the operator's increased familiarity and experience with operation of the end-cab SC.

The recommendation for future research is to conduct in-mine evaluation of transverse-mounted, end-cab SC design.

[4]Mining deeper cuts will also depend on ventilation and roof control considerations.

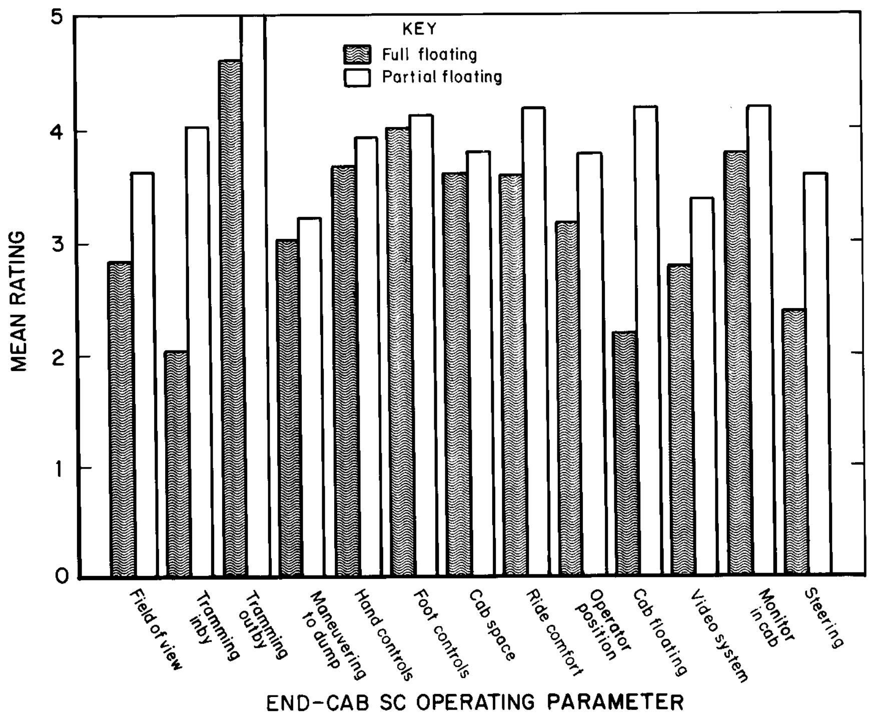

Figure 19.—Mean ratings of five test subjects comparing full-floating and partial-floating, end-cab SC (excellent = 5, very good = 4, good = 3, fair = 2, poor = 1).

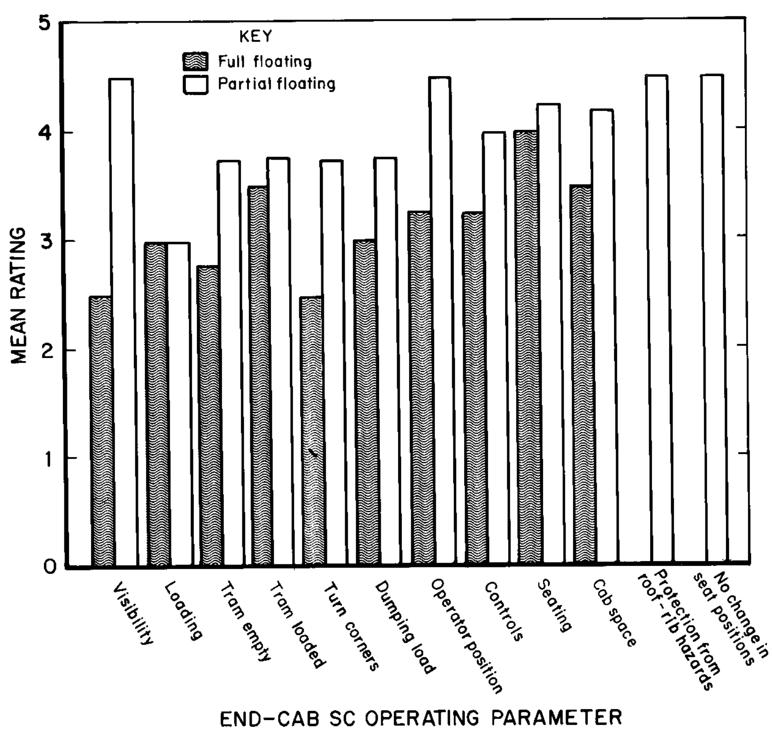

Figure 20.—Mean ratings of four experienced operators comparing standard side-cab SC with full-floating and partial-floating, end-cab SC (much better = 5, better = 4, same = 3, worse = 2, much worse = 1).

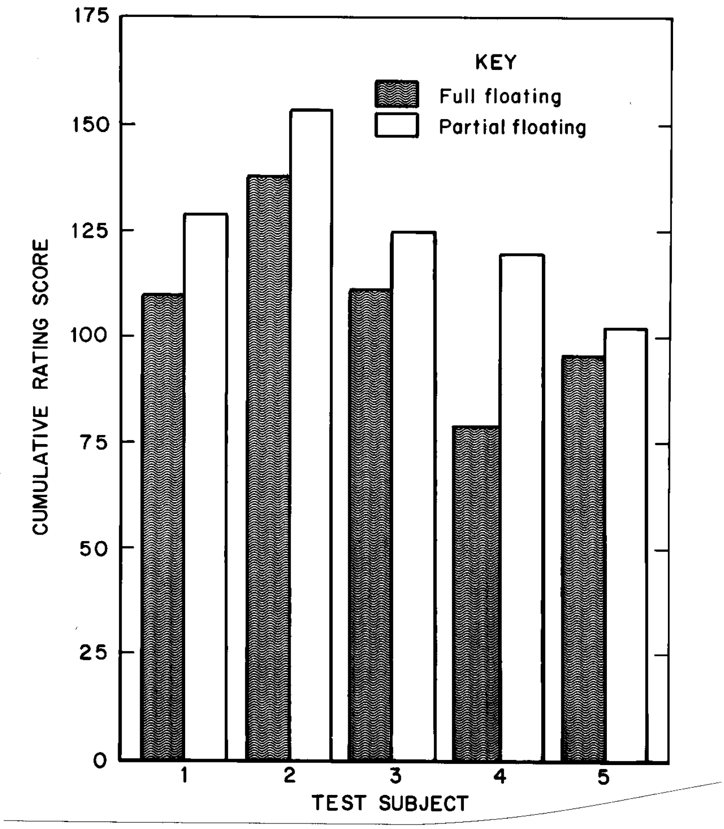

Figure 21.—Total rating scores of experienced operators comparing full-floating and partial-floating, end-cab SC. (Test subject 1 is an inexperienced operator. Test subject 2 is the operator with low-coal experience.)

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